Magnetic Damping of Solid Solution Semiconductor Alloys

Dr. Frank R. Szofran, Principal Investigator Space Sciences Laboratory NASA Marshall Space Flight Center Mail Code ES75 Marshall Space Flight Center, AL 35812

Phone: (256) 544-7777 Fax: (256) 544-8762

E-mail: frank.szofran@msfc.nasa.gov

Co-Investigators:

Prof. Dr. K.W. Benz, Dr. Arne Cröll, and Dr. Peter Dold Kristallographisches Institut der Universität, Freiburg, Germany

Dr. Sharon D. Cobb and Dr. Martin P. Volz Mail Code ES75, Marshall Space Flight Center, Alabama

Dr. Shariar Motakef

CAPE Simulations, Inc., Newton, Massachusetts

Objectives of the Investigation

The objective of this study is to conduct the Earth-based research sufficient to successfully propose a flight experiment: (1) to experimentally test the validity of the modeling predictions applicable to the magnetic damping of convective flows in conductive melts as this applies to the bulk growth of solid solution semiconducting materials in the reduced gravitational levels available in low Earth orbit; and, (2) to assess the effectiveness of steady magnetic fields in reducing the fluid flows occurring in these materials during space processing. To achieve the objectives of this investigation, we are carrying out a comprehensive program in the Bridgman and floating-zone configurations using the solid solution alloy system Ge-Si. This alloy system was chosen because it has been studied extensively in environments that have <u>not</u> simultaneously included both low gravity and an applied magnetic field. Also, all compositions have a high electrical conductivity, and the materials parameters permit high growth rates compared to many other commonly studied alloy semiconductors.

An important supporting investigation is determining the role, if any, that thermoelectromagnetic convection (TEMC) plays during growth of these materials in a magnetic field. Some compositional anomalies observed by us in magnetic grown crystals can only be explained by TEMC; this has significant implications for the deployment of a Magnetic Damping Furnace in space. This effect will be especially important in solid solutions where the growth interface is, in general, neither isothermal nor isoconcentrational. It could be important in single melting point materials, also, if faceting takes place producing a non-isothermal interface.

Microgravity Relevance

During Bridgman or floating zone growth of semiconductors, generation of destabilizing temperature gradients in the melt is unavoidable, resulting in buoyancy-induced convective mixing of the liquid phase. On Earth, this convective mixing is generally very intensive and interferes with segregation of melt constituents at the growth front. Crystal growth in low Earth orbit provides the opportunity to reduce the buoyancy-induced convective intensity; in some cases, mass transfer diffusion-controlled growth may be achieved if the residual acceleration direction and magnitude can be controlled. However, calculations and recent flight experiment results clearly

indicate that simply reducing the steady-state acceleration to values achievable in low-Earth orbit will not provide diffusion controlled growth conditions for solid solution melts ~1 cm in diameter if accelerations transverse to the growth axis are not controlled. Magnetic damping of convection in electrically conductive melts can be used to provide a higher degree of control on convection in the melt. Magnetic damping effects both buoyancy-induced and Marangoni convection and may enable diffusion controlled growth without the control of the growth direction relative to the residual steady-state acceleration. Thus, our understanding of convective influences on melt-growth processes can be further advanced, and our ability to interpret space experimental results may be significantly improved.

Results

Si, Ge, and Si-rich alloys have been grown in a monoellipsoid mirror furnace by the floating-zone technique. Ge and Ge-rich alloys have been grown by the vertically stabilized Bridgman technique in both a multi-zone tube furnace and the mirror furnace. Thus far, the sample diameters have all been in the range of 8 to 10 mm. Magnetic fields ranging up to 5 T have been used. Sample analysis has included Nomarski microscopy, four-point probe measurements, spreading resistance, quantitative electron microprobe compositional analysis, and infrared transmission spectroscopy.

TEMC induced observations include the sudden appearance of striations in Sb- and As-doped float-zone Si samples after initially growing striation free for several millimeters in fields of 1-4 T. These striations are sometimes quite periodic, with frequencies between 0.1 Hz and 10 Hz, and often exhibit a toroidal geometry, pointing to an azimuthal flow pattern. Intense convection and wave-type motion (not attributable to vibration) in Sb-doped Ge samples growing at 4 T in the mirror furnace. Calculations also show that TEMC will play an important role in the solidification of Ge-Si alloys, especially in reduced gravity.

A series of Ge-Si crystals has been grown with applied magnetic fields in both furnaces with results that suggest great sensitivity to thermal field and misalignment of the growth axis with the *g*-vector by as little as less than 1°. This is consistent with our earlier Ge results. The results have been compared with complete mixing and diffusion-controlled calculated composition profiles. Clearly, the application of a large magnetic field by itself does not ensure diffusion-controlled growth.